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Physical Environmental Conditions in the southern Gulf of St. Lawrence during 2005

Conditions environnementales physiques dans le sud du golfe du Saint-Laurent en 2005

J. Chassé, R.G. Pettipas and W.M. Petrie

Department of Fisheries and Oceans, Maritimes Region
Ocean Sciences Division, Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, N.S. B2Y 4A2

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Abstract

Physical environmental conditions in the Southern Gulf of St. Lawrence (Magdalen Shallows) during 2005 were examined from air temperature, sea ice and oceanographic data. Air temperatures were near normal during the first half of the year and above normal during the second half. Ice conditions were near normal during winter 2005. Bottom conditions were variable but tended to have be warmer over much of the deeper part of the Magdalen Shallows compared to 2004, although some coastal areas showed cooling during the year. Surface waters were significantly cooler than normal in June 2005 but changed to warmer than normal in September. This is in agreement with a decrease in the September volume of the CIL from 2004. There are warming trends at both the surface and bottom (75 m) while the salinities continue to decrease since reaching their maximum values during 2000-2002.

Resumé

On a examiné les conditions environnementales physiques dans le sud du golfe du Saint-Laurent (Plateau madelinien) en 2005 à partir des données relatives à la température de l'air, aux glaces de mer et aux données océanographiques. Les températures de l'air sont demeurées près de la normale pendant le premier semestre et ont été supérieures à la normale pendant le second semestre. L'état des glaces est demeuré près de la normale pendant l'hiver 2005. Les conditions sur le fond marin ont été variables, mais étaient généralement plus chaudes sur une grande partie de la portion plus profonde du Plateau madelinien, comparativement aux valeurs enregistrées en 2004, même si certaines zones côtières ont subi un refroidissement pendant l'année. Les eaux de surface ont été beaucoup plus fraîches que la normale en juin 2005, pour devenir plus chaudes que la normale en septembre. Cela concorde avec une diminution du volume de la CIF survenue en septembre 2004. On a observé des tendances au réchauffement tant en surface qu'au fond (75 m), même si la salinité continue de diminuer après avoir atteint des valeurs maximales entre 2000 et 2002.

Introduction

Annual assessments of the stock abundance, fishing effort, and biological characteristics of several groundfish species in the southern Gulf of St. Lawrence (Fig. 1) are undertaken by the Gulf Region of the Department of Fisheries and Oceans (DFO). The purpose of this paper is to provide environmental information as background for these assessments. Air temperatures, sea-ice conditions and ocean temperatures and salinities over the Magdalen Shallows are examined. Conditions during 2005 are described and comparisons are made to conditions in 2004 and the long-term averages. The ocean properties include surface and near-bottom temperatures from several fisheries surveys. In addition, vertical profiles and time series of the monthly mean temperatures and salinities within the southern Gulf are provided together with indices of the area of the bottom covered by specified temperatures. We begin with a description of the datasets, then provide details of the methods used to analyze the data and finally present the results.

Data

Air temperature records were available from the Magdalen Islands, Quebec, Charlottetown, Prince Edward Island (PEI) and Miramichi, New Brunswick (Fig. 1). Data for 2005 from these sites were obtained from the Environment Canada website and pre-2005 data from the climate indices database at the Bedford Institute of Oceanography (BIO). Fresh water runoff data for the Miramichi River were available from the Environment Canada website. The data are daily estimates.

Sea-ice data for 2005 covering the Southern Gulf of St. Lawrence were obtained from the Canadian Ice Service (CIS). Daily charts were examined to determine the position of the ice edge (10% concentration) at specified dates through the winter. Digital versions of the weekly ice charts from CIS were used to update the gridded sea-ice database at BIO (Drinkwater et al. 1999). This database contains the concentrations by ice type and the area covered (in tenths) within each 0.5° latitude by 1° longitude region in the Gulf of St. Lawrence for the years 1963 to present. From this data, we have obtained estimates of the date of first presence of sea ice, last presence and duration of ice during the winter of 2005.

Extensive geographic coverage of surface and near-bottom temperatures during 2005 for the southern Gulf of St. Lawrence was available from four main surveys. The mackerel survey was conducted in June (Fig. 2a), the snow crab survey from August to September, the Northumberland Strait Survey in August to September and the annual multi-species survey in September (Fig. 2b). Temperature and salinity data were collected with a conductivity-temperature-depth (CTD) instrument during the mackerel, multi-species and Northumberland Strait surveys. Approximatively 50 CTD stations were taken on or adjacent to the Magdalen Shallows during the mackerel survey, 180 stations during Northumberland Strait Survey and 139 stations on the multi-species survey. The snow crab surveys obtained near-bottom temperatures with a thermistor attached to the trawl at 354 stations. Other temperature and salinity data from the southern Gulf in 2005, obtained from research surveys and ships-of-opportunity, were obtained from the Marine Environmental Data Service (MEDS) in Ottawa, Canada's national oceanographic data archive. Pre-2005 data were taken from the historical hydrographic database maintained at BIO. This database contains an edited version of the entire MEDS holdings for the region.

Methods

Anomalies, defined as the difference from the long-term averages, were estimated for all of the environmental data. The averages were calculated over a 30-year period (1971-2000) similar to that used by the meteorologists and adopted for use with oceanographic data by DFO's Fisheries Oceanography Committee (FOC) and the Scientific Council of the North Atlantic Fisheries Organization (NAFO).

The surface and near-bottom temperatures from data collected during each of the surveys were interpolated onto a 0.1° x 0.1° latitude-longitude grid using an objective analysis procedure known as optimal estimation. This method is similar to other objective techniques such as kriging but offers the advantage that the interpolation is 4-dimensional; i.e. three space dimensions, two horizontal and one vertical, and the time dimension, rather than 2-dimensional (the two horizontal dimensions). In this study the surveys were treated as synoptic and no interpolation in time was carried out. The details of the procedure are found in Drinkwater and Pettipas (1996). For the surveys using CTDs, the maximum profile depth from the CTD trace for each station was assumed to be at the bottom. Checks against bathymetric charts were carried out to ensure that no large errors occurred as a result of this assumption. The bottom temperature data were then smoothed for the purpose of contouring. Note that the smoothing routine tends to spread out sharp near-bottom temperature gradients (e.g. those near the coast), and thus the gradients depicted in the plots are not as sharp as in reality.

Long-term monthly climatological means of the surface and near-bottom temperatures were estimated at each grid point based upon optimal estimation using all available data for the years 1971-2000 in the historical temperature, salinity database at BIO. Temperature anomalies were derived by subtracting these climatological means from the 2005 values. A negative anomaly indicates that the 2005 temperature was colder than the long-term mean and a positive anomaly indicates that it was warmer than the long-term mean. We also examined the change in temperature since the previous year by subtracting the 2004 optimally-estimated temperatures from the 2005 estimates. A negative value indicates that 2005 was cooler than 2004, a positive value that it was warmer.

From the optimally estimated bottom temperatures obtained during the groundfish survey, the area of bottom covered by each 1°C temperature bin was estimated for the entire series (1971-2005). For this, the temperature at each grid point was assigned the area of bottom associated with that particular grid point. These have been used to estimate the area of bottom covered by water of <0°C and <1°C.

In addition, annual mean temperature and salinity profiles for 2005 were determined within the eastern and western regions of the Magdalen Shallows from the BIO database. All available data within each of these areas were averaged by month at standard depths (0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 250, and 300 m where possible). An "annual" anomaly profile was determined by averaging over the available monthly anomalies, regardless of whether there were data available in 1 or 12 months of the year. Time series of monthly mean temperatures and salinities at representative depths for each area are also provided. Long-period trends are shown in the plots of these monthly means. They are the 5-year running averages of the "annual" anomalies.

Results

Air Temperatures

The mean air temperatures on the Magdalen Islands were around or slightly warmer than their long-term average during the first 6 months and significantly warmer from July to December in 2005 (Fig. 3). Similar air temperature conditions also were observed at Charlottetown (PEI) and Miramichi (NB). The annual means were significantly above normal at all three sites (Magdalen Islands, anomaly of 1.1°C; Miramichi, 0.8°C; Charlottetown, 0.7C). The time series at each of the sites show similar trends (Fig. 4, 5). The longest record is from Charlottetown, which began in 1873. It shows that in most years prior to 1930 the annual mean temperatures were below the 1971-2000 average. The 1950s show warmer than normal conditions and oscillations of about a 15-year period can be seen until the late 1990's. Recent temperatures have been above normal. 1999 has the highest temperature on record at all three sites.

Runoff

The time series of the Miramichi River freshwater runoff is shown in Fig. 6. The annual average runoff increased from a value of 77 m^3/s in 2004 to 162 m^3/s in 2005. It was the third highest value since 1960 and the highest value of the last 26 years. The mean runoff in 2005 was then 42 m^3/s above the long-term average of 120 m^3/s.

Sea-Ice

The times of first presence show ice forming initially along the coastal regions of the Magdalen Shallows and spreading eastward (Fig. 7). By mid January, ice had covered a large portion of the Shallows for some period of time. Subtracting the long-term (1971-2000) mean indicates that the time of first ice was earlier that normal along the coast of new Brunswick and over the western part of the Shallows, while around normal appearance time was observed along the Laurentian Channel in 2005 (Fig. 8, top panel). The last presence of ice was near the 30th of April around Miscou Island and in Chaleur Bay (Fig. 7), approximately 10 to 15 days later than normal and was around normal over the middle of the Southern Gulf (Fig. 8, bottom panel). Occurrence of ice was also observed slightly later than normal along the coast of Cape Breton. The duration of sea ice is the number of days ice was present. It is not the simple difference between the dates of first presence and last presence since the ice may come and go. The ice duration varied from a high of over 130 days near Miscou Island to around 80 days along the edge adjacent to the Laurentian Channel (Fig. 9). This resulted in durations that were around 5-10 days longer than normal over the Western Magdalen Shallows to 5-10 days shorter than normal along the Laurentian Channel in 2005. Ice volume was near normal during 2005 (figure not shown).

Hydrographic Conditions

Bottom Temperatures

The mackerel survey in June 2005 shows a large area of the central Shallows covered by temperatures <1°C but only a small portion with temperatures <0°C (Fig. 10). From the centre of the Shallows, bottom temperatures tended to increase towards the shallower, nearshore regions and towards the deeper Laurentian Channel. This is because

in the Gulf of St. Lawrence throughout the summer, cold temperatures are found at intermediate depths (50-150 m), sandwiched between warm solar-heated upper layer waters and the relatively warm, salty deep waters in the Laurentian Channel that originate from the slope water region off the continental shelf. These cold waters are known as the cold intermediate layer (CIL). Although the deeper waters are warmer than the CIL, their density is higher because of higher salinities. In winter, the CIL merges with the upper layer as the latter cools. The primary origin of the waters in the CIL is from atmospheric cooling of the water within the Gulf of St. Lawrence in winter with an additional 35% from the advection of cold Labrador Shelf water through the Strait of Belle Isle (Petrie et al., 1988).

Relative to the long-term (1971-2000) mean, the bottom temperatures in June 2005 were colder than normal over most of the coastal waters of the Southern Gulf and the central Magdalen shallows. The rest of the Southern Gulf was warmer than normal (Fig. 10). The largest negative anomalies where observed in the Eastern Northumberland Strait (-6°C) and around Miscou Island (-2°C). The largest positive anomalies (> 2°C) were located on the eastern side of the Southern Gulf, along the border of the Laurentian Channel. Relative to the June survey in 2004, temperatures had cooled in Chaleur Bay, the eastern part of Northumberland Strait and the coast of Cape Breton, while the rest of the Southern Gulf shows that bottom waters had warmed during the year (Fig. 11), especially in the area north of Magdalen Islands.

The longest running survey on the Magdalen Shallows is the multi-species survey (1971-present, formerly the groundfish survey). The measurements were combined with those from the Northumberland Strait survey to obtain a quasi complete picture of the Southern Gulf. Bottom temperatures in 2005 ranged from <1°C to over 17°C (Fig. 12). Most of the Shallows (50-80 m) were covered by temperatures <1°C. Usually, the bottom is still covered with some water below 0°C but none was observed in September 2005. The decrease from June (mackerel survey) to September (multi-species survey) of 2005 in the amount of near-bottom waters <1°C is typical, due to seasonal warming.

Bottom temperature anomalies in September 2005, from the mouth of Chaleur Bay to Western Cape Breton and all around PEI, were significantly below normal while the rest of the Southern Gulf, including Chaleur Bay and the deeper parts along the Laurentian Channel, exhibit warmer than normal conditions (Fig. 12). The negative anomalies were below -3°C in the area offshore of Miramichi Bay and on the eastern side of Northumberland Strait. The large negative anomalies are unusual for these areas. The highest positive anomalies appeared in Chaleur Bay (+3°C), St. Georges Bay (+4°C) and on the eastern Part of the Southern Gulf along the Laurentian Channel (+1-2°C).The coastal anomalies must be viewed with caution, however, since the largest uncertainties in the bottom temperature fields are in the near shore regions. There are two main reasons for this. First, there tends to be greater temporal variability at shallower depths because they lay close to the thermocline, i.e. the strong vertical gradient in temperature. In these regions the mixed layer may extend to the bottom one day and be near the surface the next day as conditions respond to wind storms. This produces large variability in the near-bottom temperatures in shallow regions. Second, the optimal estimation routine projects horizontal gradients to the coast if there are few data nearshore. This can lead to erroneous extrapolation of data in regions of strong horizontal temperature gradients.

Relative to 2004, bottom temperatures during the 2005 multi-species survey were significantly cooler in the coastal area extending from Miscou Island to St. Georges Bay, including the coastal waters north of PEI (Fig. 13). The remaining portion of the

Southern Gulf, including Chaleur Bay, exhibit warmer conditions than in 2004. The region offshore of Miramichi Bay was especially cooler with a temperature departure of -4°C. The eastern Northumberland Strait was significantly cooler in 2005 than in 2004 with a difference of over 5°C around Pictou Island.

From the gridded temperature data, time series of the area of bottom covered by each 1°C interval were estimated. We have plotted the time series of the area of the bottom covered by each temperature bin in Figure 14. In 2005, there was no water covered by temperatures <0°C which contrasts with the cold period observed in the 1990's.

Surface Temperatures

In addition to the near bottom temperatures, we have investigated the surface (0-5 m) temperatures from the surveys. In the June mackerel survey, surface temperatures over the Shallows ranged from 8°C in the Laurentian Channel region to over 11°C around at the mouth of Miramichi Bay (Fig. 15). The 2005 surface values were significantly cooler than the long-term means over the most of the Southern Gulf, except along the northern part (Laurentian Channel) and the western coast of Cape Breton. The largest negative anomalies (-5°C) appeared along the north shore of PEI. Temperatures significantly increased, relative to 2004, in the area close to the Laurentian Channel while the waters around PEI have cooled during the year (Fig. 16).

The surface temperatures from the multi-species survey in September ranged from 10°C off Gaspé to over 20°C in the Northumberland Strait (Fig. 17). Contrary to June, the surface waters over most of the region were warmer than their long-term means over most of the Southern Gulf while the surface water above the Laurentian Channel were cooler than normal (Fig. 17). There was a substantial increase in the surface temperatures over most of the Southern Gulf between the multi-species surveys from 2004 to 2005 except the water above the Laurentian Channel in the east the domain (Fig. 18). The area off northeast PEI shows the maximum increase with a difference of +5°C. It should be noted, though, that June and September are months of rapid warming and cooling respectively in the surface waters of the Gulf; there might be some bias in these inter-annual and long-term differences because of differences in weather and slight differences in the timing of the survey between years.

Time series of the temperature anomalies at 10 m over the western and eastern Magdalen shallows (see Fig. 19 for the area boundaries used in the temperature analysis) were constructed from the data of the mackerel survey (Fig. 18b). The anomalies were corrected to take account for the timing of the survey. This was done by removing the seasonal cycle from the data. The results show that year 2005 had temperatures in June similar to the two previous years and still slightly below the long term means.

Monthly Mean Temperatures and Salinities

Vertical profiles of the annual mean temperature and salinity anomalies for the southern Gulf were calculated from all available data. To determine if there were spatial differences in temperature trends across the Magdalen Shallows, we divided it into eastern and western regions for the purposes of our analysis (Fig. 19). The monthly mean temperatures and salinities at standard depths were estimated by averaging all of the available data within each region regardless of when in the month it was collected. Similarly, no adjustments were made for the spatial distribution of data or the amount of

data that contributed to the average. In some cases the "average" was based upon only one measurement while in other months it was based on over 100 stations. The long-term (1971-2000) means for each area were calculated and then subtracted from the individual monthly means to obtain an anomaly. Then, annual means were constructed by averaging the available monthly profiles of the anomalies. Only the annual mean profiles are discussed here. Because of the possible limited amount of data from which the averages were calculated or the spatial variability in temperature within the regions, any one point or profile may not be truly representative of "average" conditions for the year. Interpretation of the anomalies therefore must be viewed with caution. While no reliance should be placed on any individual monthly or yearly anomaly, persistent features are considered to be real.

Data for 2005 over the western Magdalen Shallows were available for 10 months: March to December. The annual anomaly profile tends to show slightly warmer than normal temperatures at the surface, around normal between 25 and 150 m and colder than normal below 150m (Fig. 20). Lower-than-normal average salinities were observed down to 125 m in 2005. The average salinity anomaly is around -0.2 (Fig. 21).

On the eastern side of the Shallows, data were available in 5 months in 2005: March, June, July, September and November. The annual mean anomaly profile of temperature shows warmer than normal conditions down to 75 m and around normal temperatures for the rest of the water column (Fig 22). Salinities on the eastern side tended to be significantly lower than normal down to 120m and saltier at greater depths (Fig. 23).

In addition to the anomaly profiles, time series of the monthly mean temperatures and salinities at 75 m and the surface were generated. The former depth is considered representative of the near-bottom within both regions. Note that data are not available in every month. There are less salinity data and hence the long-term trends for salinity are not as reliable as for temperature. Although there are some differences in the temperatures in the two sides of the Shallows at 75 m, the long-term trends in both regions are similar (Fig. 24). Relatively warm conditions persisted around the mid-1950s, near 1970, and in the early 1980s separated by colder-than-normal periods. The late 1980s and early 1990s exhibit the longest period of below average temperatures in the entire record. Then the late 1990s have seen warming from these low temperatures. The time series show a decline on both sides of the Shallows over between 2000 and 2004 then increased again at the end of 2004 and during 2005. The time series at the surface show higher variability than at 75 m (Fig. 25). This is because of the importance of atmospheric heat fluxes in heating or cooling the surface waters. These fluxes can undergo large changes from month to month. The surface temperature trends are somewhat similar between the two sides of the Shallows but not as strong as at 75 m. Surface layer waters were warm in the late 1940s and 1950s, near normal through most of the 1960s, warm around 1980 and slightly above normal through the 1980s and into the 1990s. The late 1990s showed higher positive temperature anomalies than the previous decade, but the temperatures started to slowly decline after year 2000 until the end of 2004 and the beginning of 2005 when they increased again. The salinities at 75 m show several differences between the two regions but this may be due in part to the small number of samples. In recent years there appears to be slightly below normal salinities near bottom on both sides of the Shallows (Fig. 26). At the surface, salinities through the late 1990s appear also to be fresher-than-normal (Fig. 27). Then, they increase to slightly above normal values after year 2000 until the end of year 2004 when they declined again.

CIL Volume

A volume index of the cold intermediate layer (CIL) was developed for the month of September using the information from the groundfish survey. It consists in calculating the volume of water that has a temperature below 1°C in the Southern Gulf. During September 2005, the CIL volume was 1352 km^3 and was below the long-term mean (1971-2000) of 1903 km^3 . (Fig. 28). This is a slight decrease compared to 2004 when the index was 1647 km^3. The index has been decreasing since 2003 when it was above the long term mean. The 1999 value represented the first year since the early to mid-1980s that volume index was below normal suggesting warmer conditions in the Southern Gulf. Since then, there has been five years with a below average quantity of cold water. Gilbert and Pettigrew (1997) found high correlations between the variability in the Gulf wide CIL core temperatures and air temperatures along the coast of western Newfoundland, suggesting the possible importance of atmospheric forcing in determining the temperature and extent of the CIL waters in the Gulf. These air temperatures have been mostly above or close to normal since 1999, which may explain in part the lesser quantity of cold water in the Southern Gulf.

Summary

Physical environmental conditions in the southern Gulf of St. Lawrence (Magdalen Shallows) during 2005 were examined from air temperature, sea ice and oceanographic data. Air temperatures were around normal during the first half of the year and above normal during the second half. Ice conditions were around normal during winter 2005. Bottom temperature conditions were variable but tended to have warmed over much of the deeper part of the Magdalen Shallows compared to 2004, although some coastal areas showed cooling during the year. Surface waters were significantly cooler than normal in June 2005 but changed to warmer than normal in September. This is in agreement with a decrease in the volume of the CIL from 2004 measured in September. There are warming trends at both the surface and bottom (75 m) while the salinities continue to decrease since their maximum values around 2000-2002.

Acknowledgements

We acknowledge Tom Hurlbut at GFC for providing the CTD data from the multi-species survey and Mark Hanson for the data from the Northumberland Strait survey. The mackerel survey data were collected by scientists at IML in Mont Joli, Quebec, headed by F. Gregoire. We extend a special thanks to the scientists, technicians and crew who collected all of these data. We thank Dr K. Drinkwater for providing the schematic of this document and the text of an earlier similar document that was used as a template.

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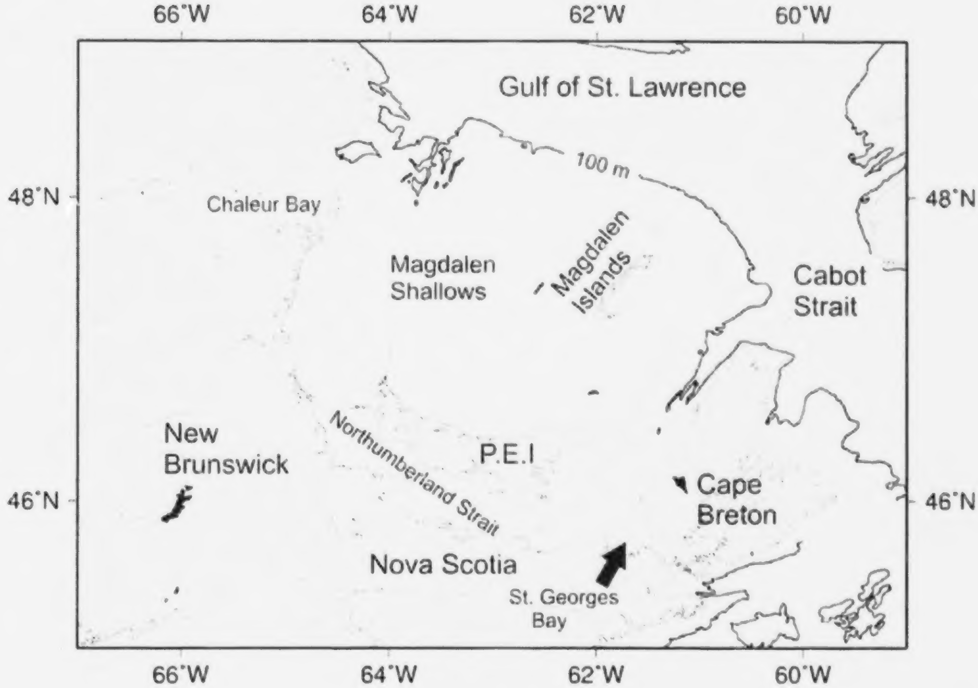


Fig. 1. Chart of the southern Gulf of St. Lawrence showing geographic and topographic features referred to in the text.

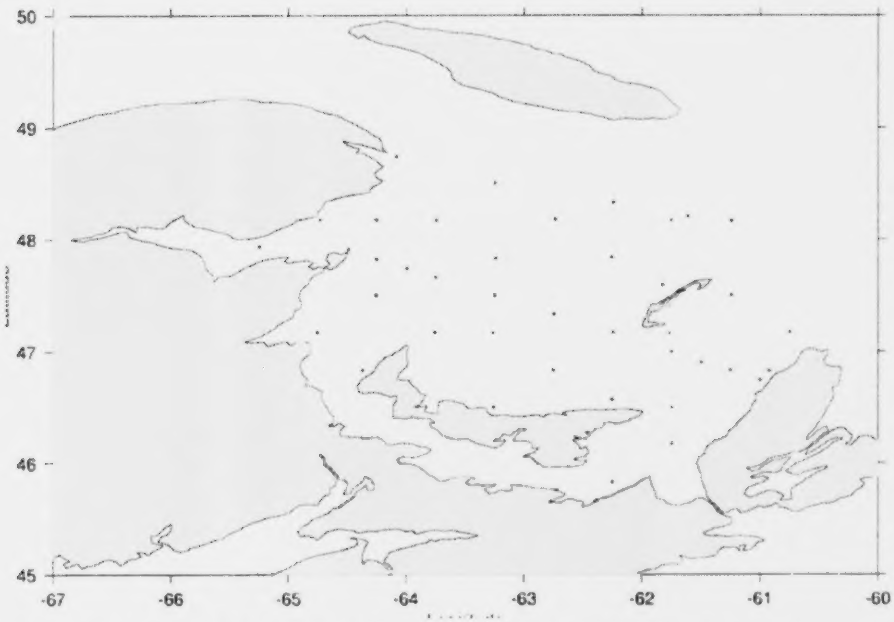


Fig. 2a. The location of the CTD stations during the June 2005 mackerel survey.

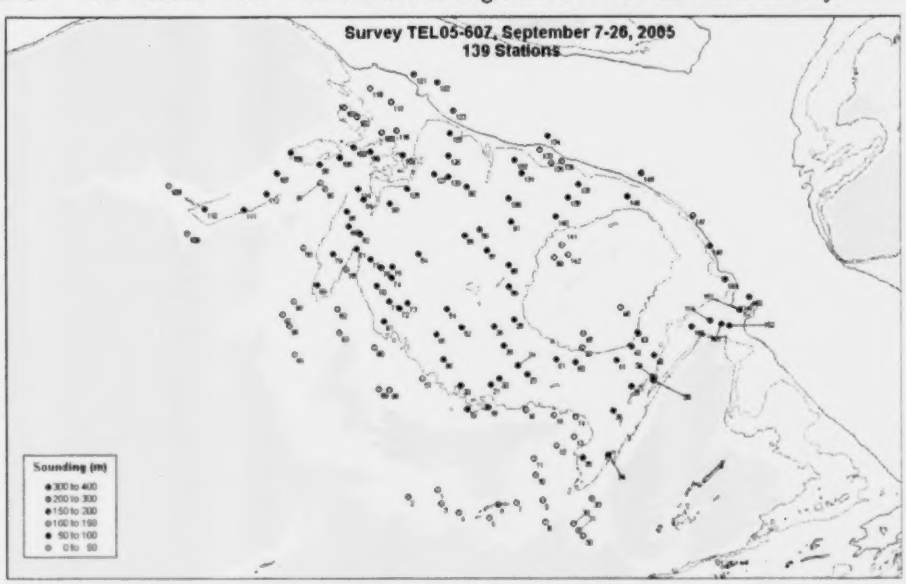


Fig. 2b. The location of the CTD stations during the September 2005 multi-species survey.

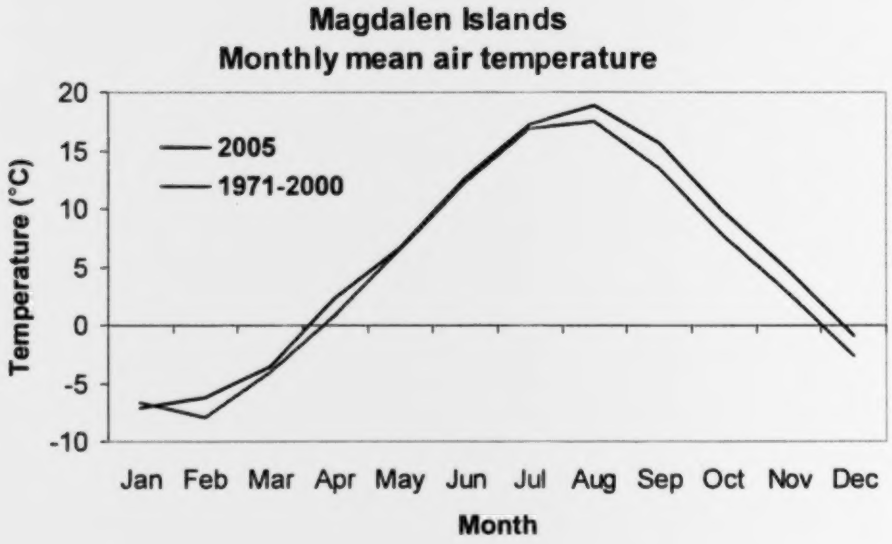


Fig. 3. The monthly mean air temperatures for the Magdalen Islands in 2005 and their long-term averages (1971-2000).

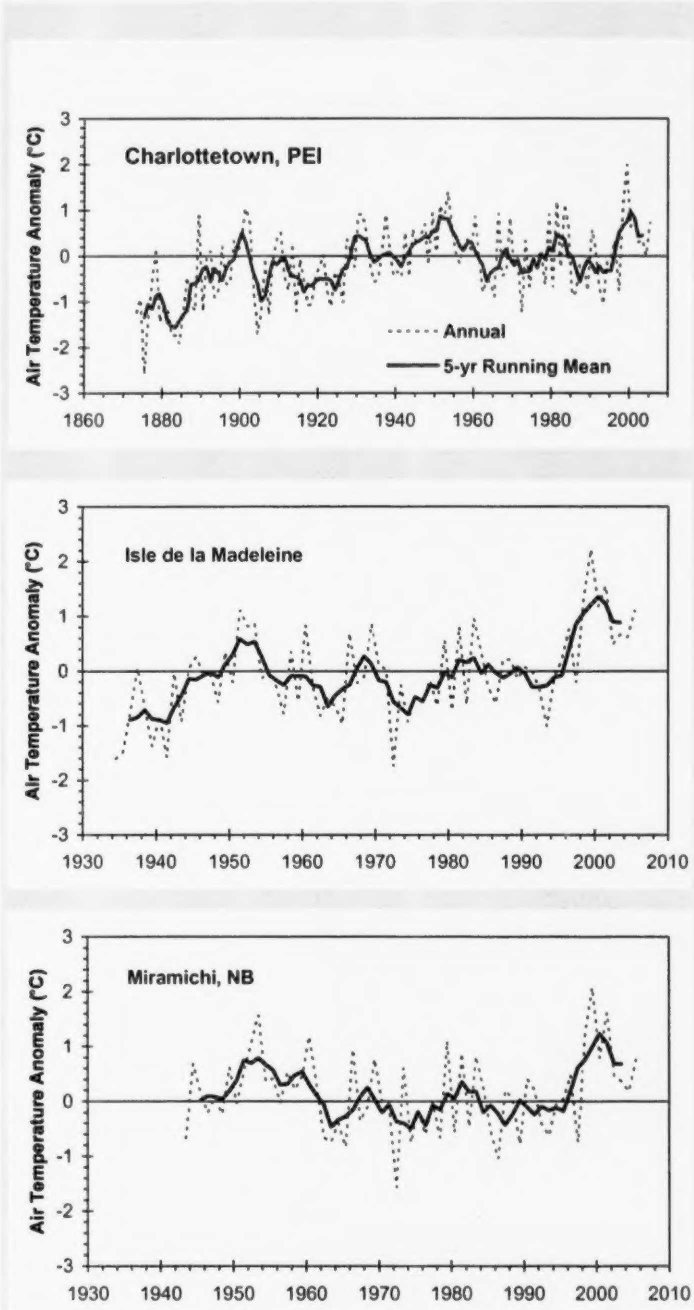


Fig. 4. Time series of the annual air temperatures (dashed) and their 5-year running means for Charlottetown, the Madgalen Islands and Miramichi. Note the time scale on the Charlottetown plot is different.

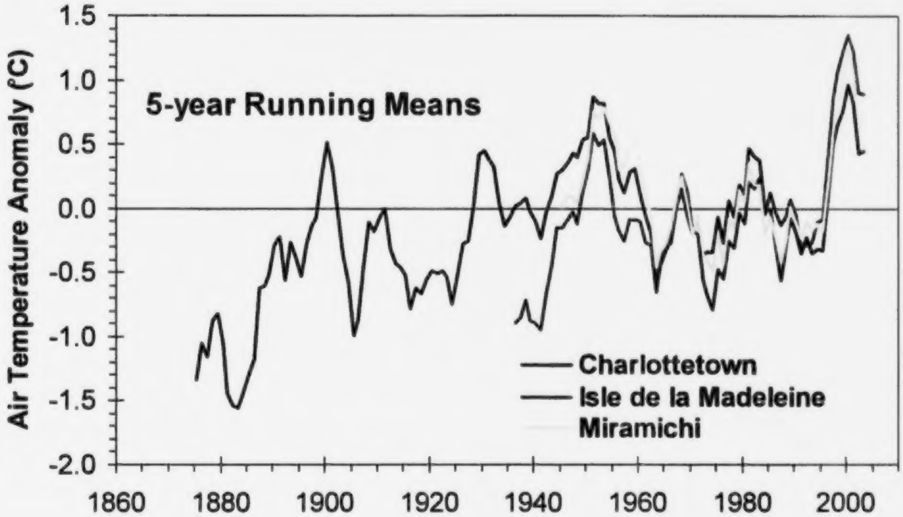


Fig. 5. The time series of the 5-year running means of air temperature anomalies at three sites in the southern Gulf of St. Lawrence.

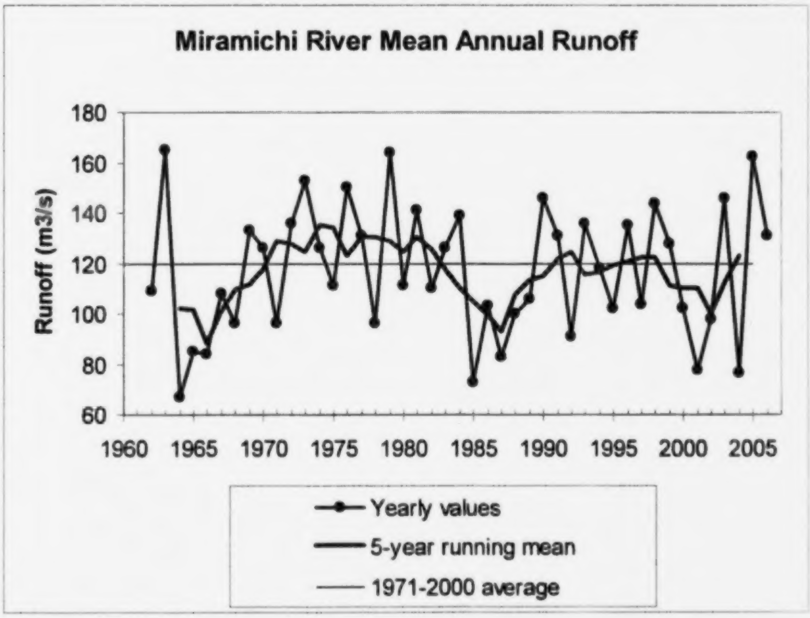


Fig. 6. The Miramichi River freshwater runoff. The 2005 value is above the long term mean.

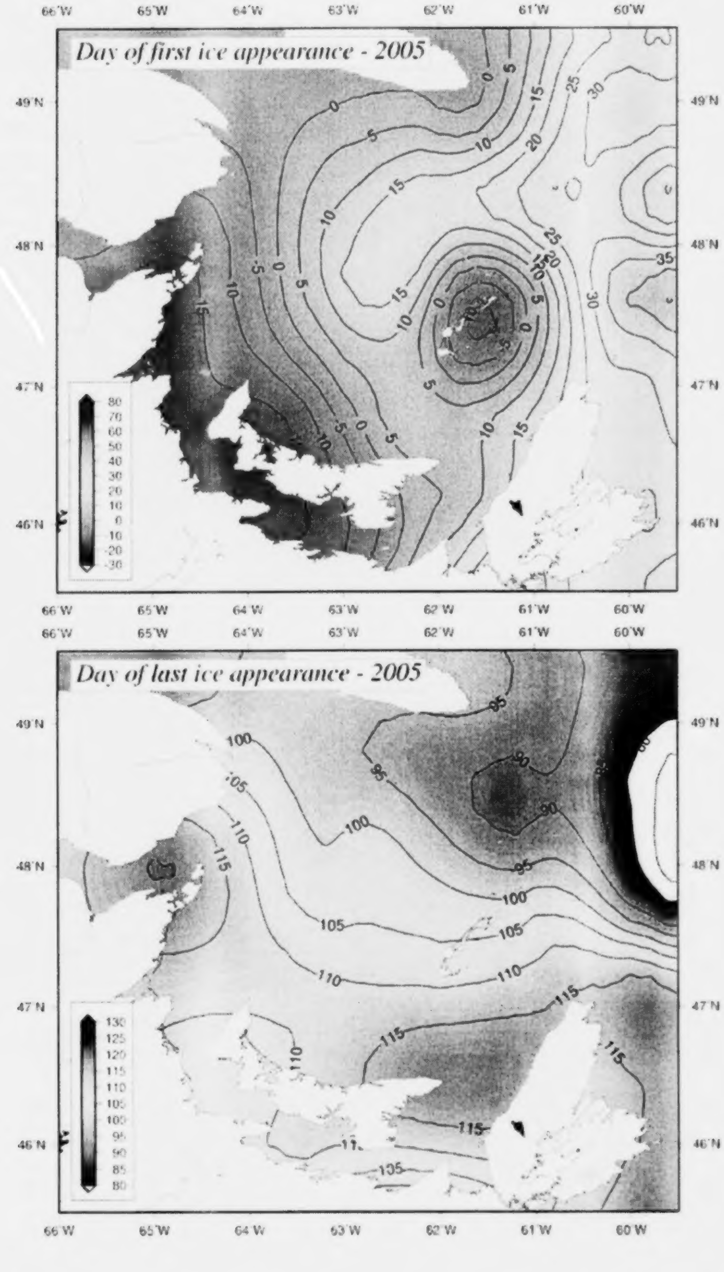


Fig. 7. The date of first (top panel) and last (bottom panel) presence of ice in days from the beginning of the year.

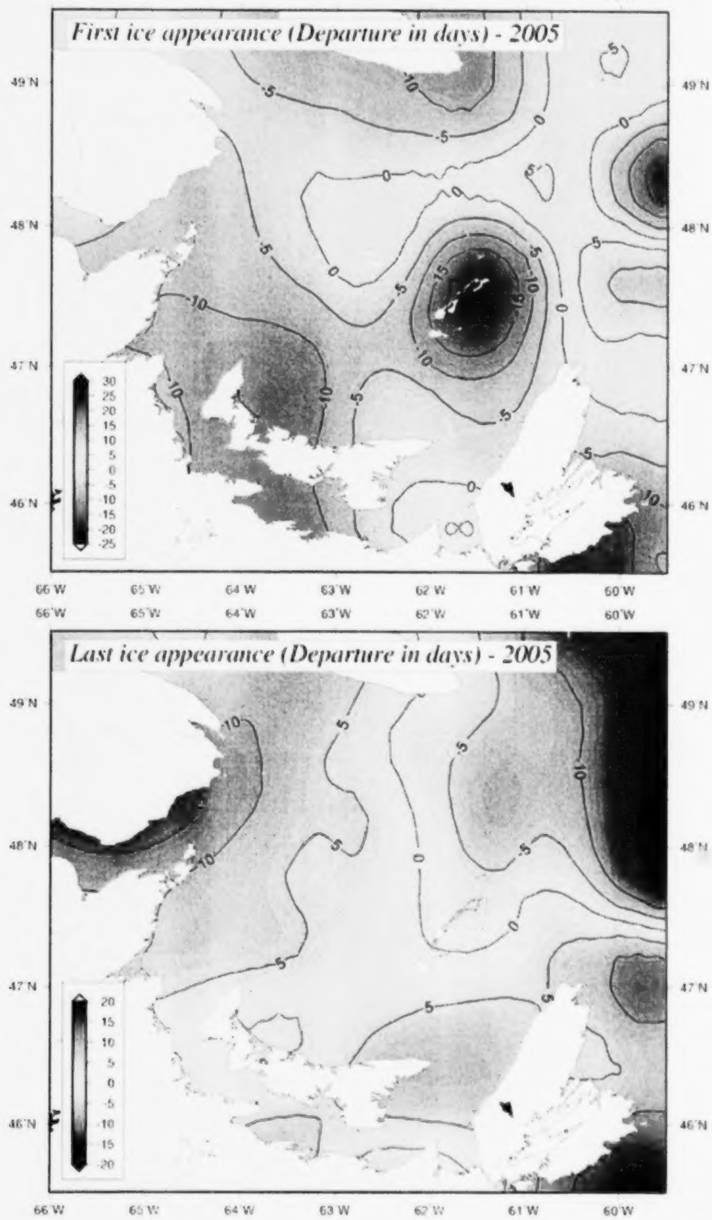


Fig. 8. The anomalies relative to the1971-2000 average of the first (top panel) and last (bottom panel) presence of sea ice in days. The blue regions in the top panel indicate where ice appeared early and, in the bottom panel, when it disappeared late (negative anomalies).

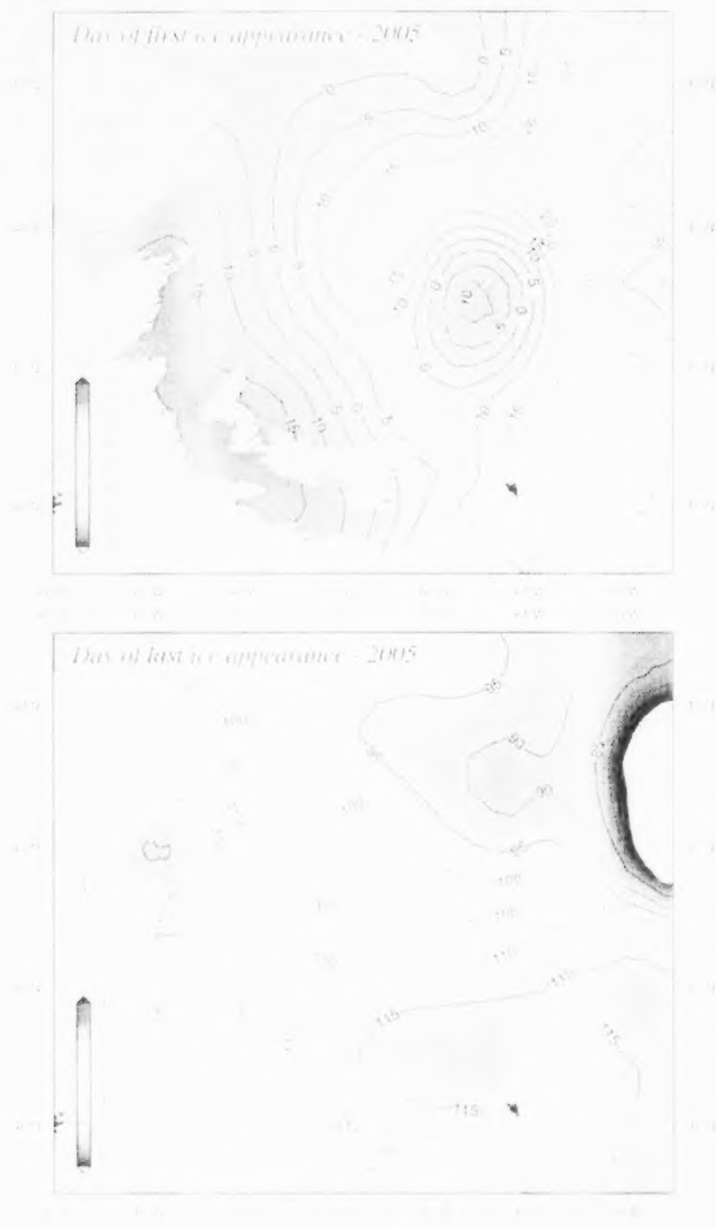


Fig. 7. The date of first (top panel) and last (bottom panel) presence of ice in days from the beginning of the year.

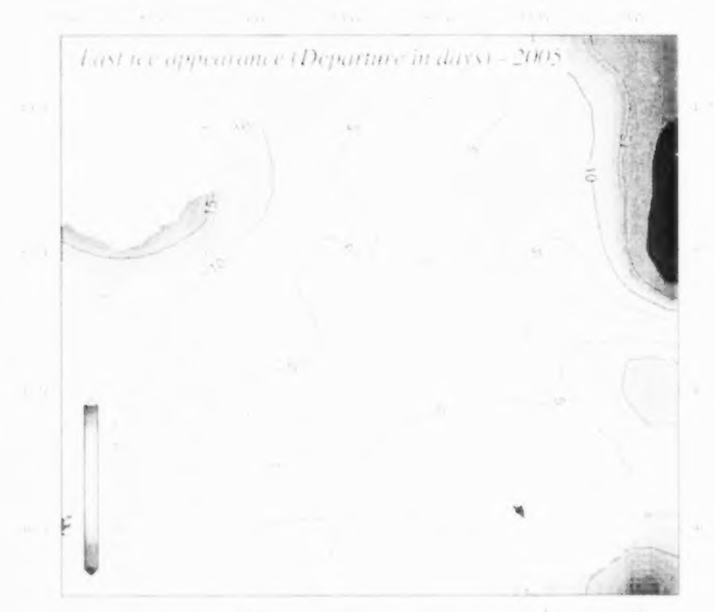


Fig. 8. The anomalies relative to the1971-2000 average of the first (top panel) and last (bottom panel) presence of sea ice in days. The blue regions in the top panel indicate where ice appeared early and, in the bottom panel, when it disappeared late (negative anomalies).

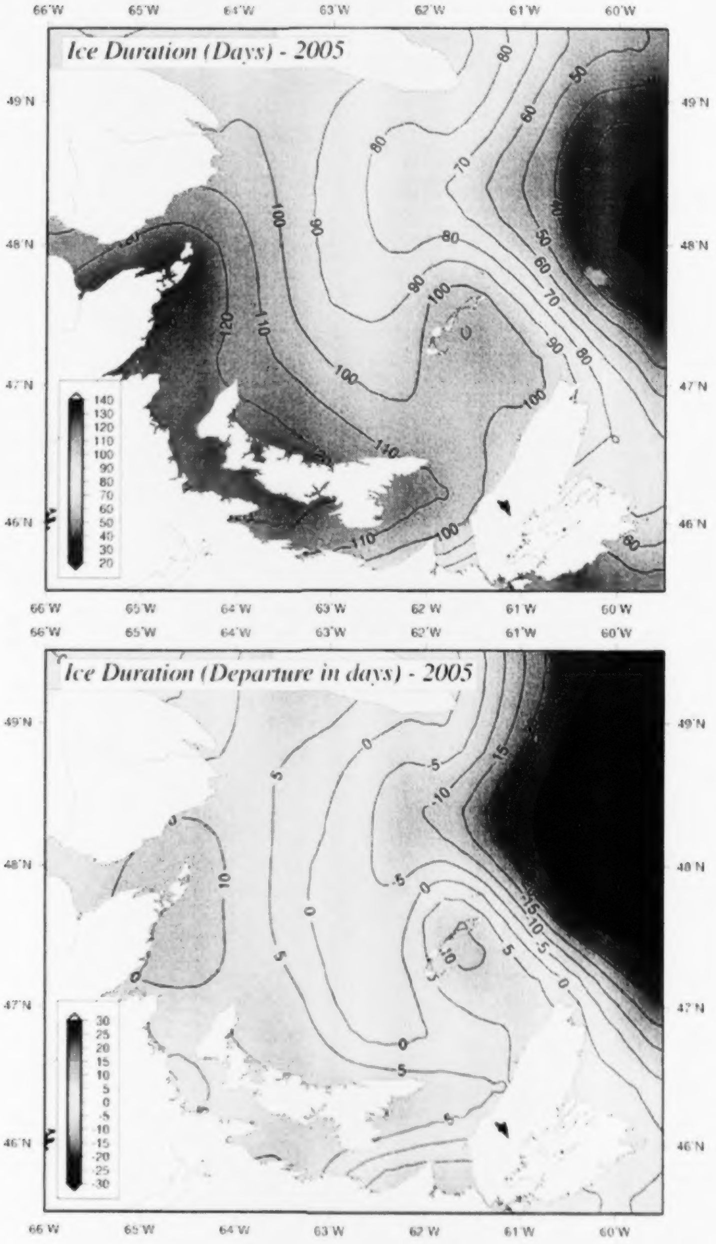


Fig. 9. The duration of sea-ice in days during 2005 (top panel) and their anomalies relative to the 1971-2000 average in days (bottom panel).

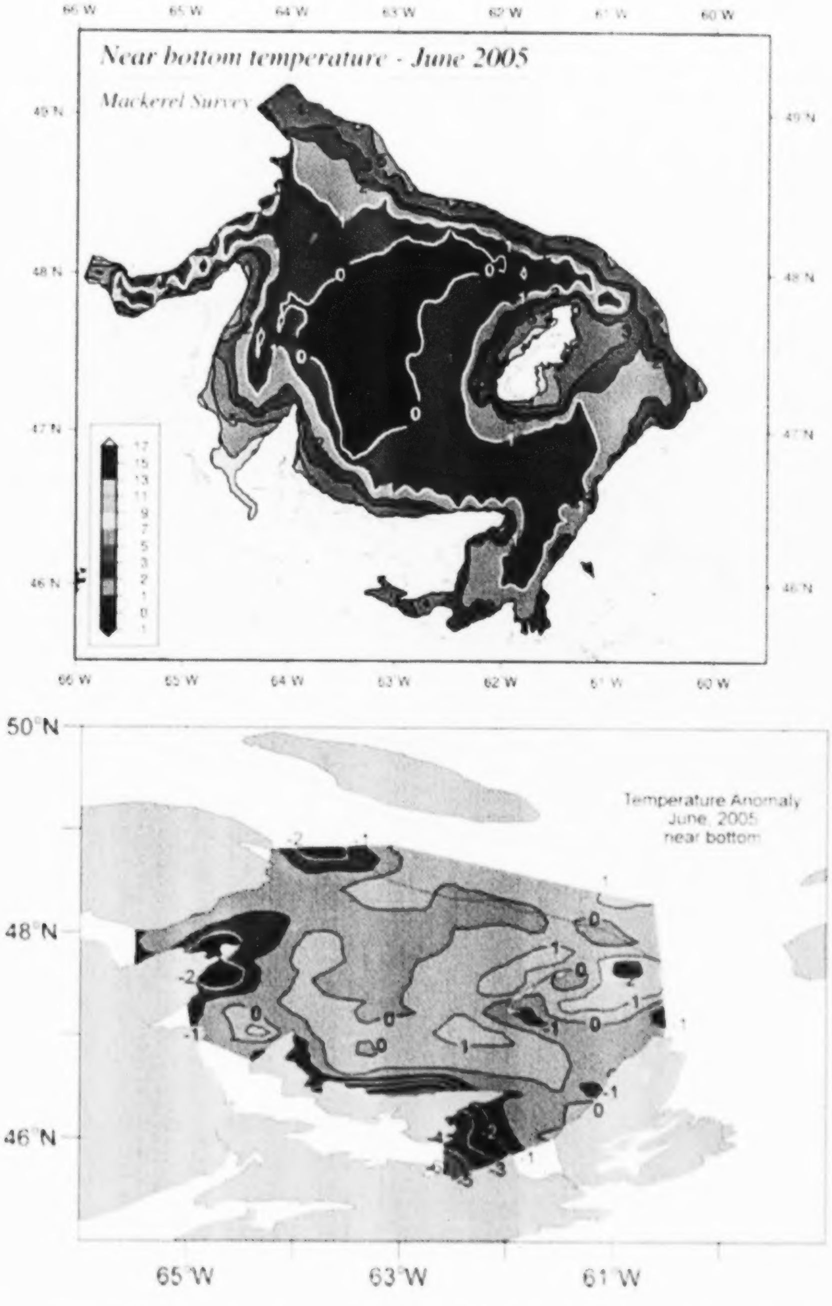


Fig. 10. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

Fig. 9. The duration of sea-ice in days during 2005 (top panel) and their anomalies relative to the 1971-2000 average in days (bottom panel).

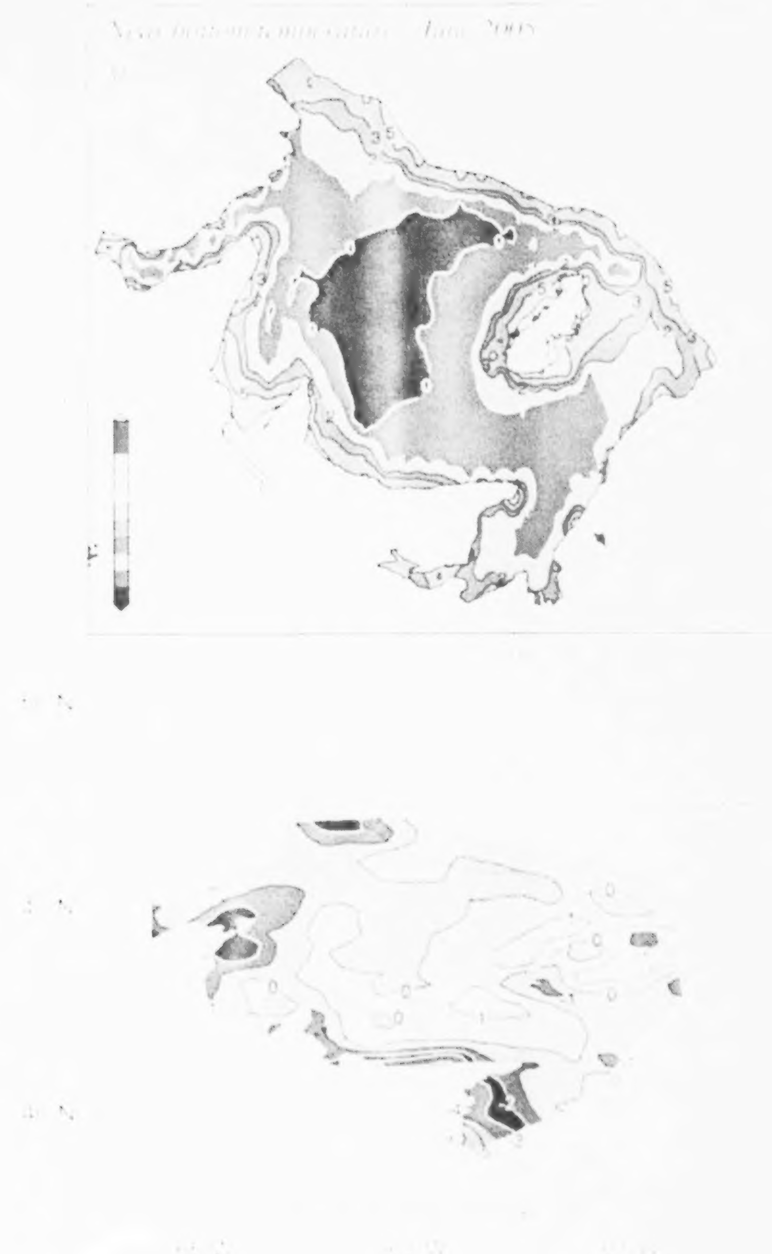


Fig. 10. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

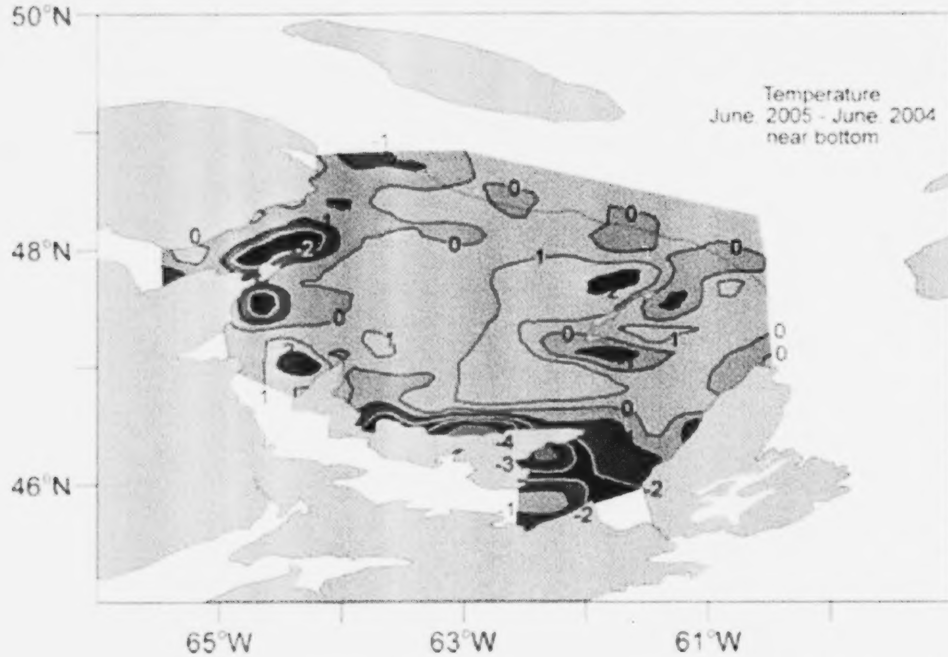


Fig. 11. The difference between the 2005 and 2004 near-bottom temperatures in the southern Gulf of St. Lawrence for the June mackerel survey. Positive values (red) indicate temperatures in 2005 had warmed and negative values (blues) that they had cooled.

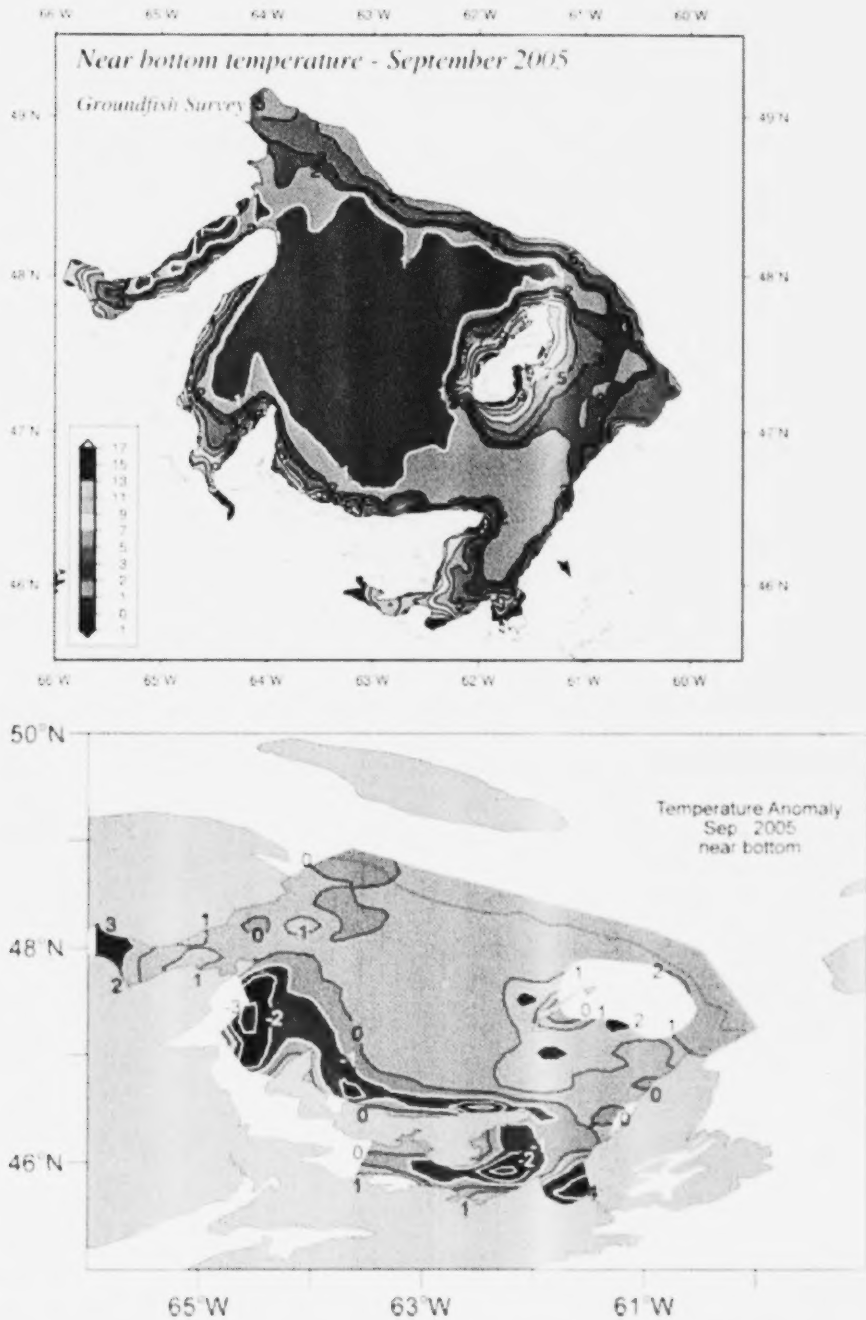


Fig. 12. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 September multi-species survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

Fig. 11 The difference between the 2005 and 2004 near-bottom temperatures in the southern Gulf of St. Lawrence for the June mackerel survey. Positive values (red) indicate temperatures in 2005 had warmed and negative values (blues) that they had cooled.

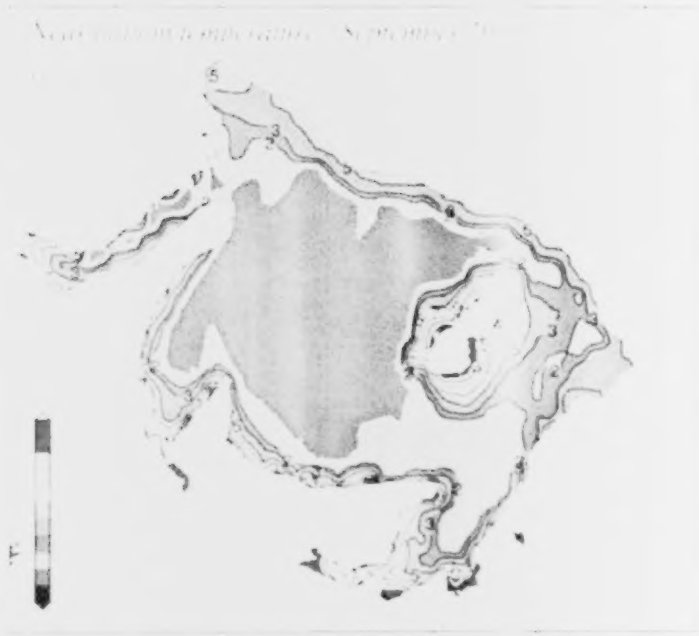


Fig. 12. Near-bottom temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 September multi-species survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

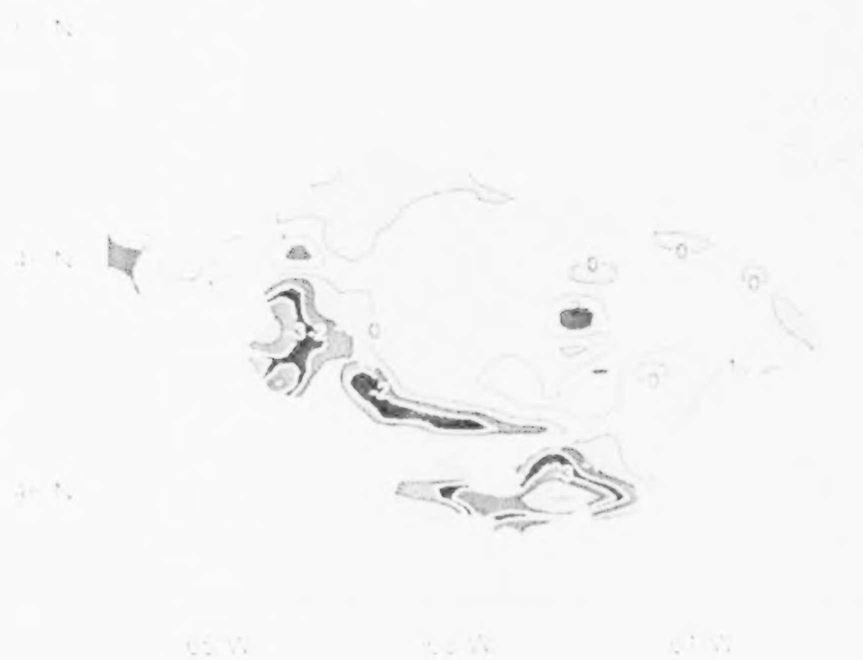


Fig. 13. The difference between the 2005 and 2004 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values indicate temperatures in 2005 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue.

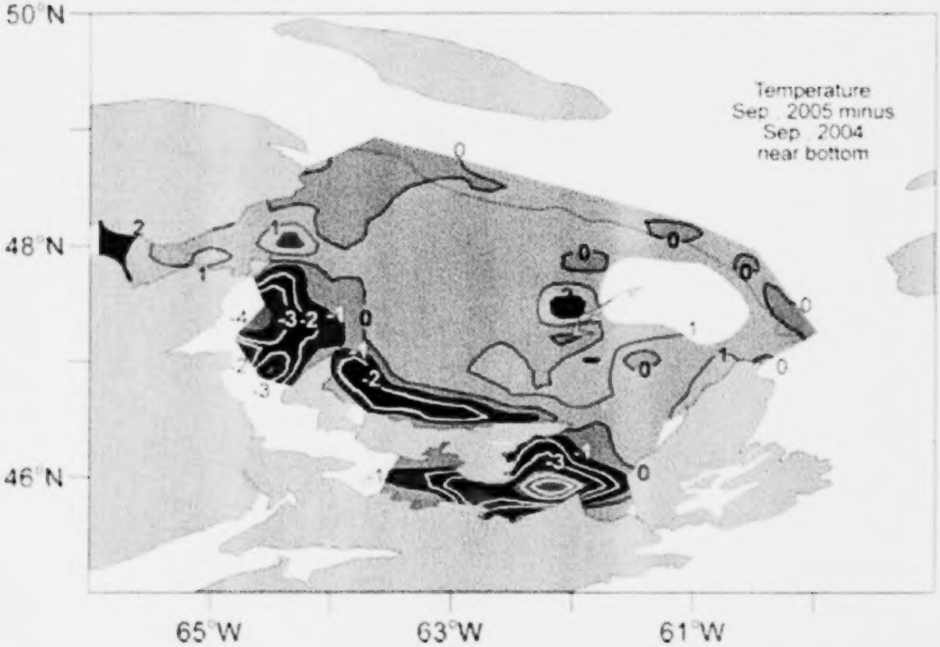


Fig. 13. The difference between the 2005 and 2004 temperature fields in the southern Gulf of St. Lawrence for the September groundfish surveys. Positive values indicate temperatures in 2005 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded blue.

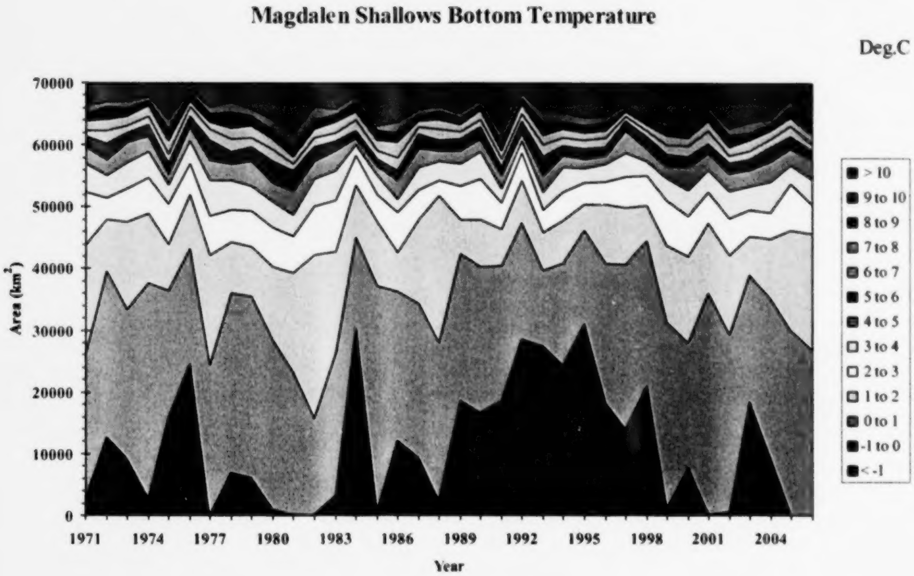


Fig. 14. Time series of the area of the Magdalen Shallows covered by different temperature bins in September.

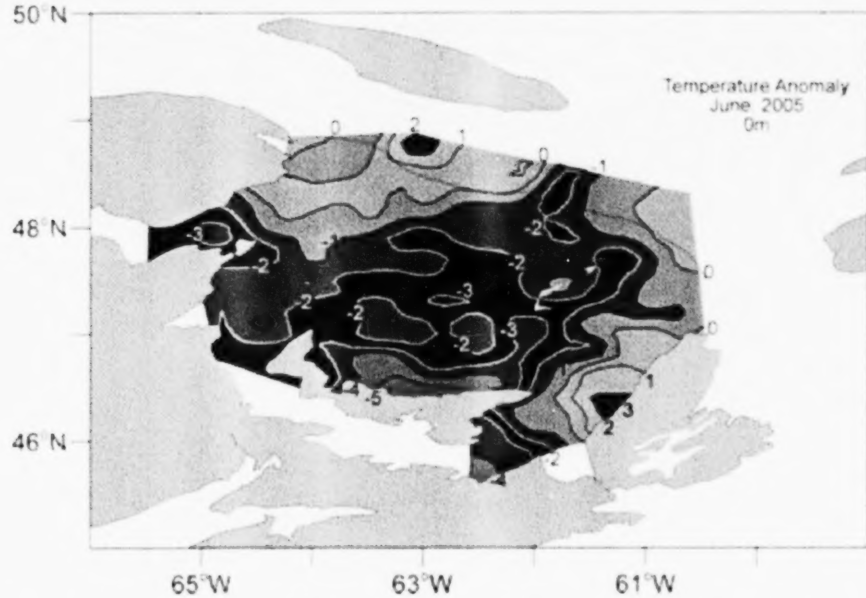


Fig. 15. Surface temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

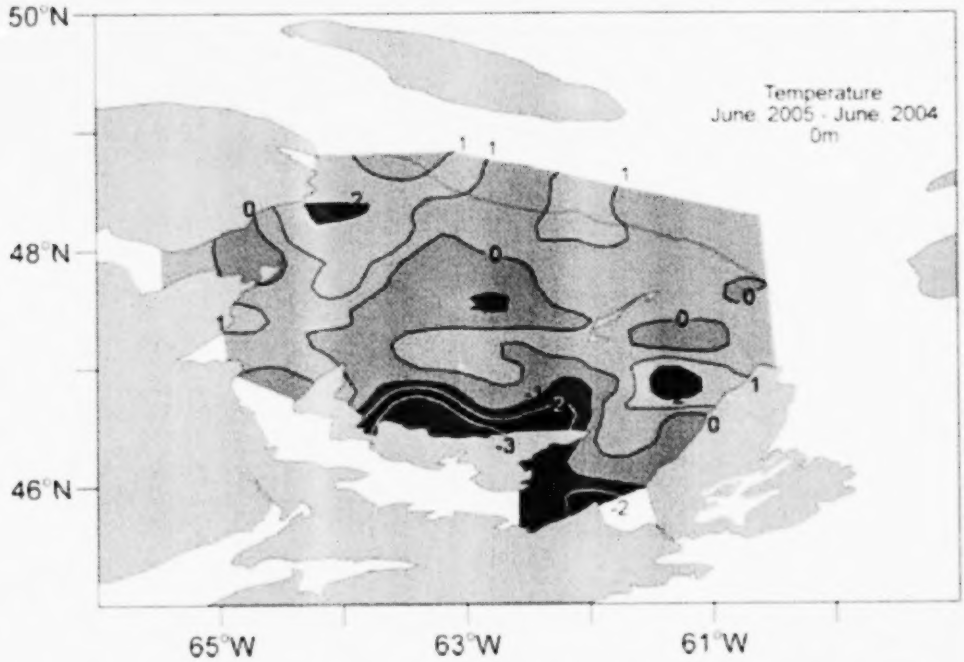


Fig. 16. The difference between the 2005 and 2004 surface temperatures in the southern Gulf of St. Lawrence during the June mackerel surveys. Positive values indicate temperatures in 2005 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded in blue.

Fig. 15. Surface temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 June mackerel survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

Fig. 16. The difference between the 2005 and 2004 surface temperatures in the southern Gulf of St. Lawrence during the June mackerel surveys. Positive values indicate temperatures in 2005 had warmed and negative values that they had cooled. Regions where cooling occurred are shaded in blue.

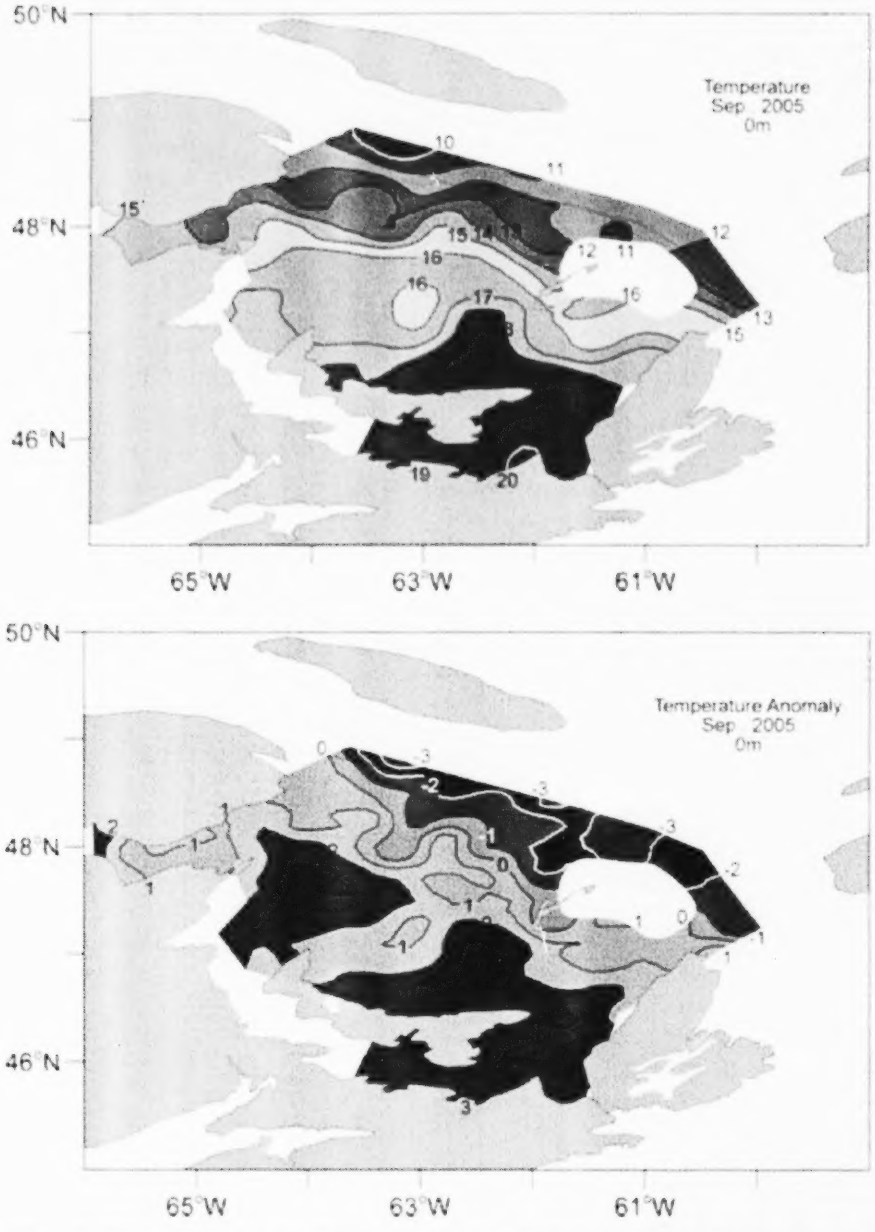


Fig. 17. Surface temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 September multi-species survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

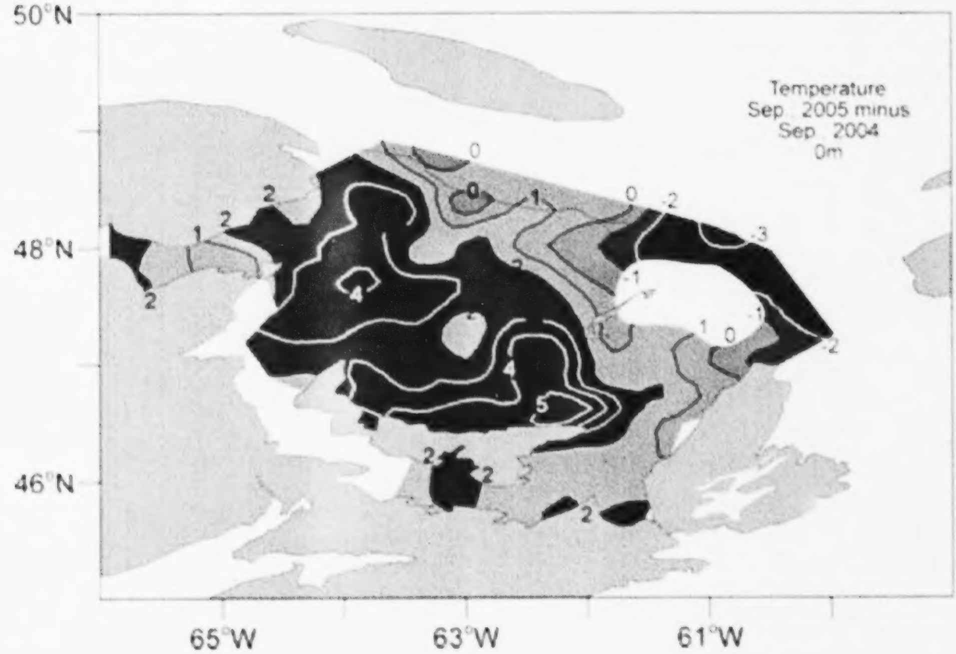


Fig. 18. The difference between the 2005 and 2004 surface temperatures in the southern Gulf of St. Lawrence during the September groundfish surveys. Positive values indicate temperatures in 2005had warmed and negative values that they had cooled. Regions where cooling occurred are shaded in blue.

Fig. 17 Surface temperatures (top panel) and their departure from the long-term (1971-2000) means (bottom panel) in the southern Gulf of St. Lawrence during the 2005 September multi-species survey. Regions of colder-than-normal temperatures are shaded blue in the bottom panel.

Fig. 18. The difference between the 2005 and 2004 surface temperatures in the southern Gulf of St. Lawrence during the September groundfish surveys. Positive values indicate temperatures in 2005had warmed and negative values that they had cooled. Regions where cooling occurred are shaded in blue.

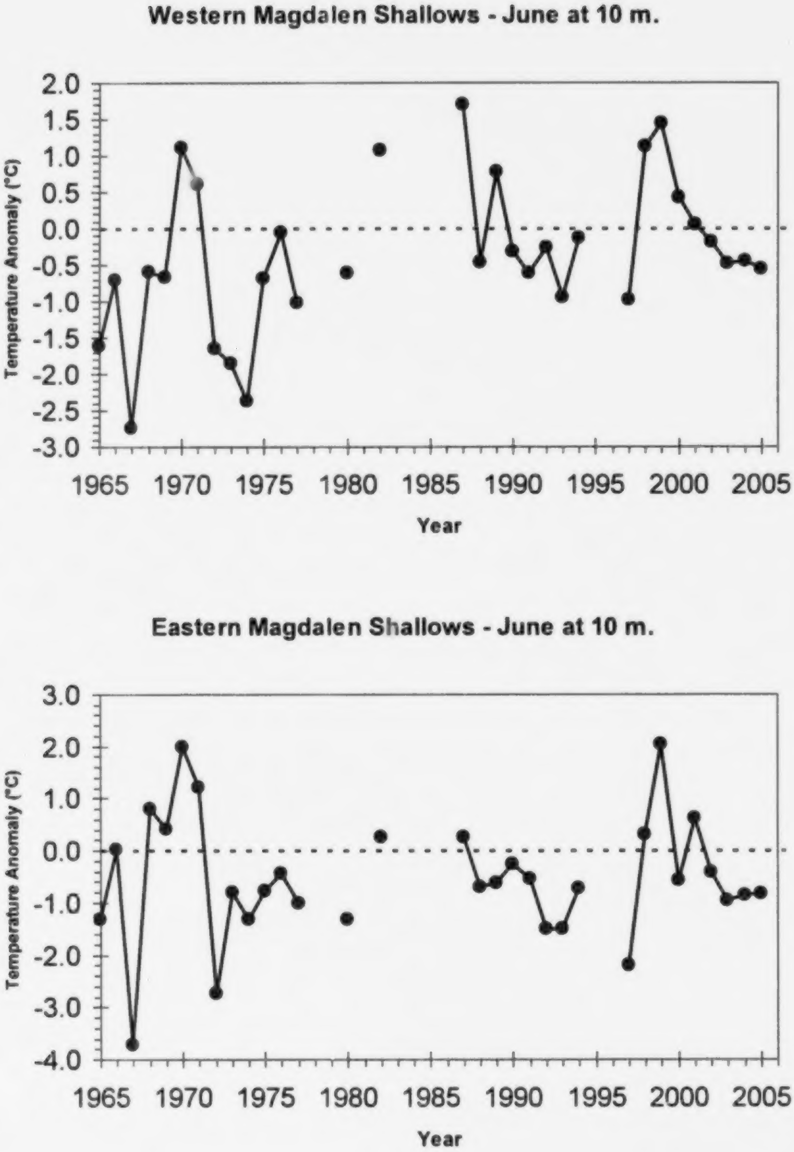


Fig. 18b. The time series of the June anomalies of temperature at 10 m for the western (top panel) and eastern (bottom panel) Magdalen Shallows. The anomalies have been corrected to account for the timing of the survey.

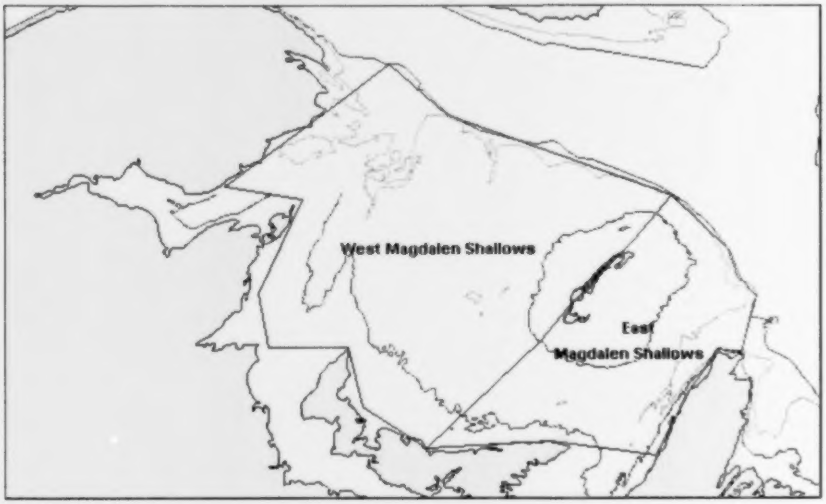


Fig. 19. The boundaries of the two regions of the Magdalen Shallows for which temperature and salinity analyses were carried out.

W. Magdalen Shallows

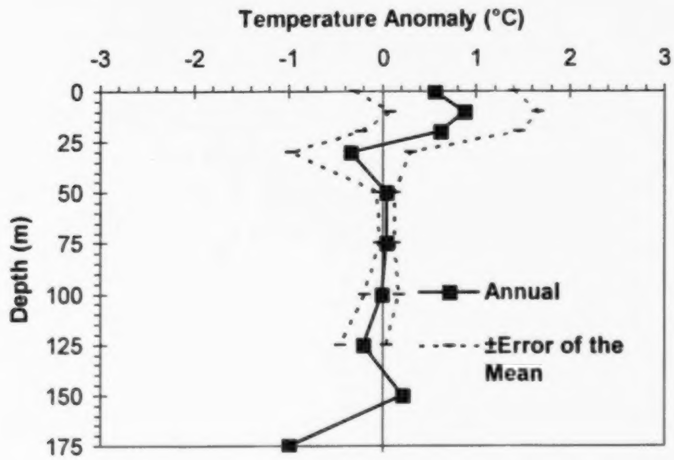


Fig. 20. The vertical profiles of the 2005 annual mean temperatures within the western Magdalen Shallows region.

W. Magdalen Shallows

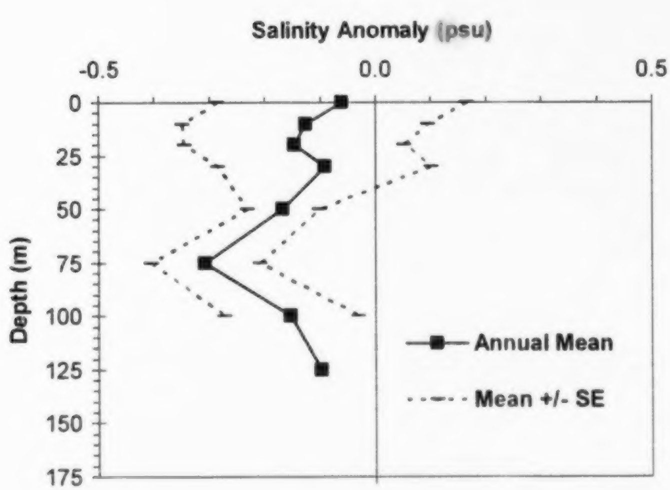


Fig. 21. The vertical profiles of the 2005 annual mean salinities within the western Magdalen Shallows region.

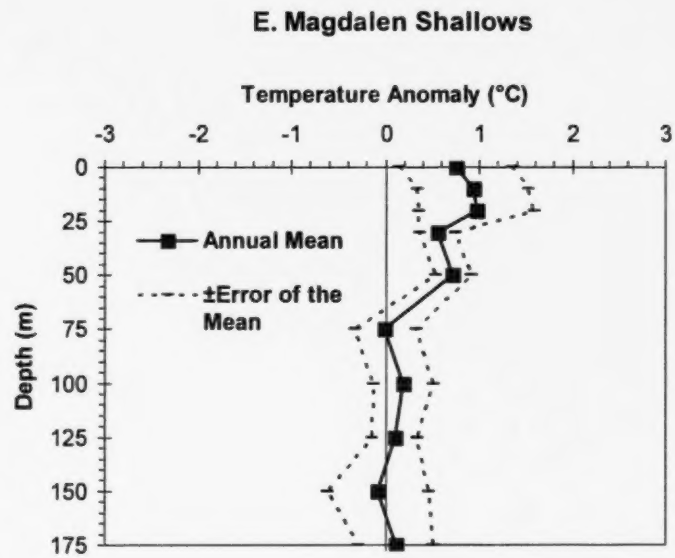


Fig. 22. The vertical profiles of the 2005 annual mean temperatures within the eastern Magdalen Shallows region.

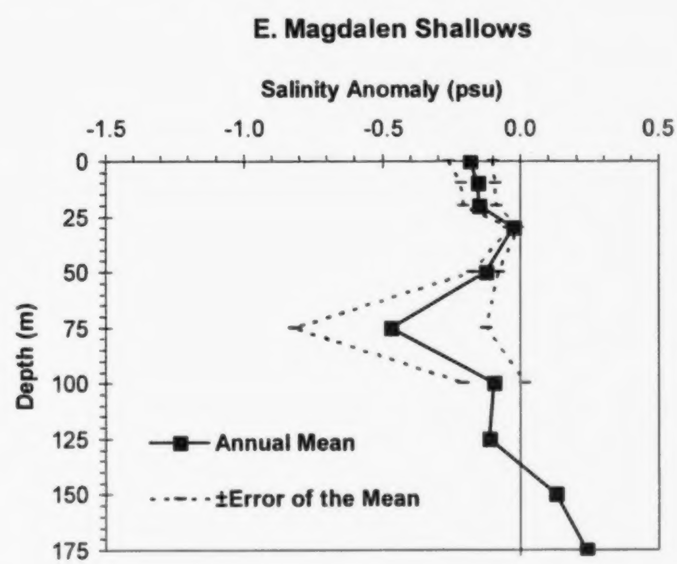
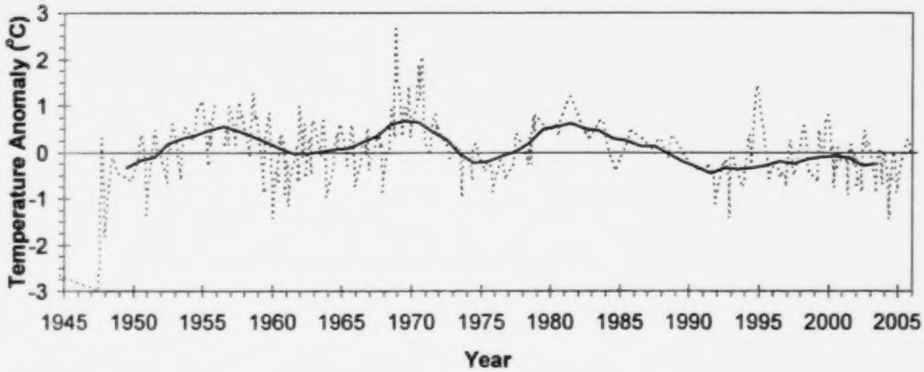


Fig. 23. The vertical profiles of the 2005 annual mean salinities within the eastern Magdalen Shallows region.

W. Magdalen Shallows - 75 m.



E. Magdalen Shallows - 75 m.

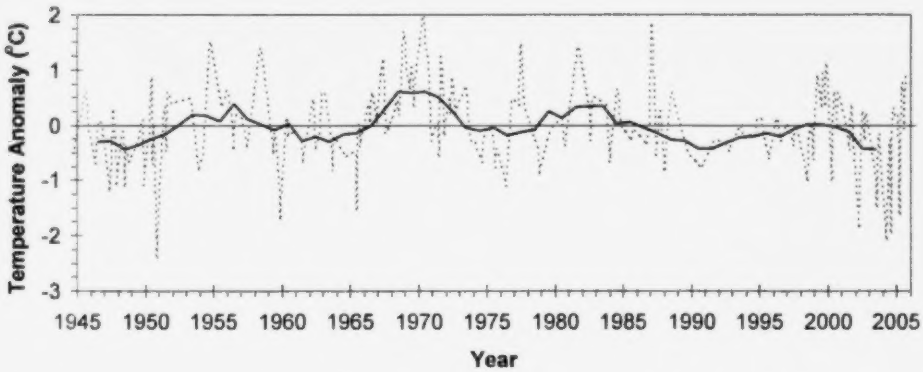


Fig. 24. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of temperature at 75 m for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

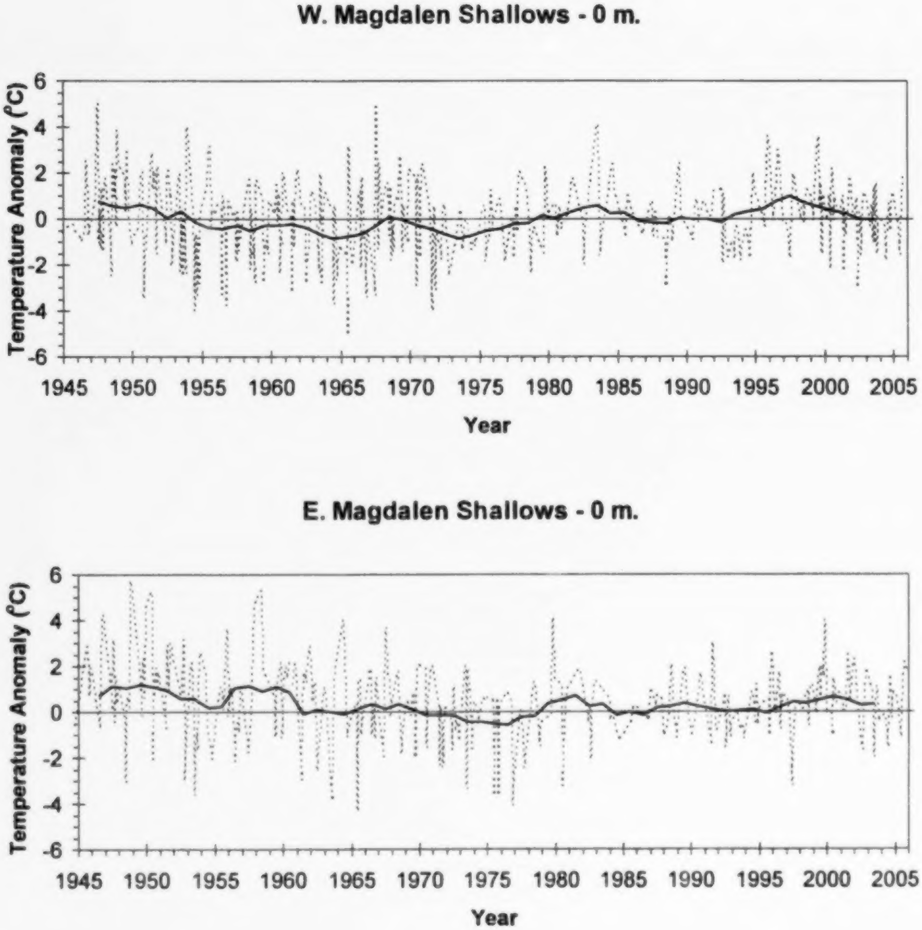


Fig. 25. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of the surface temperature for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

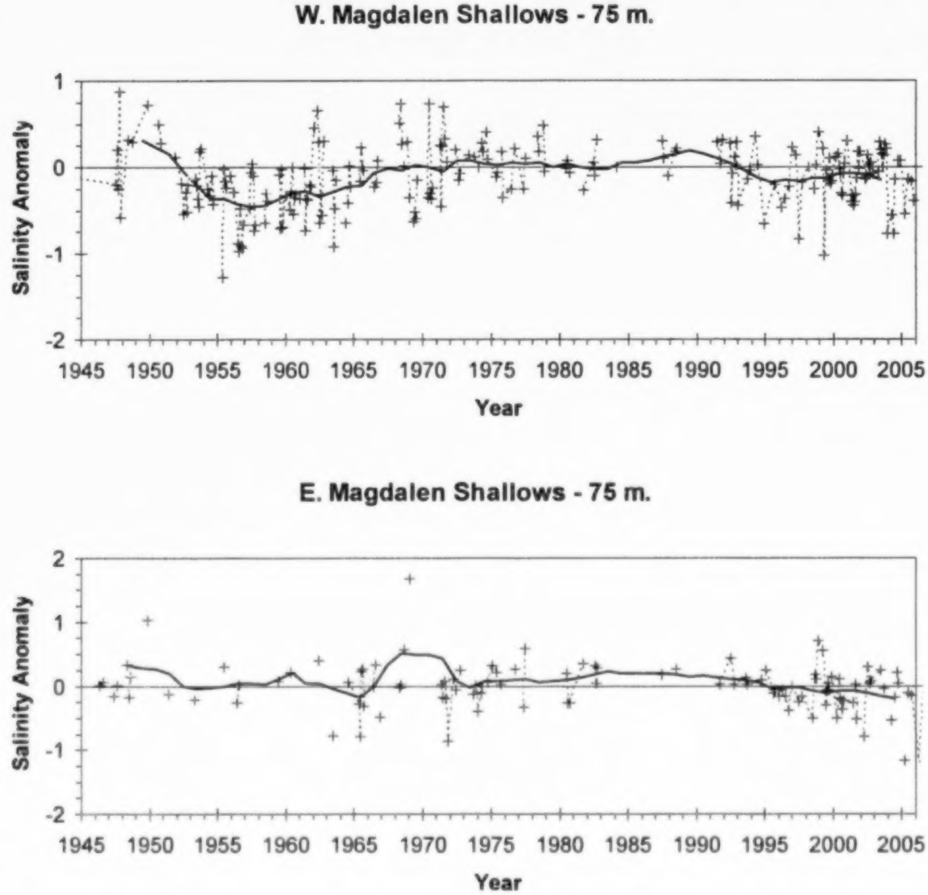
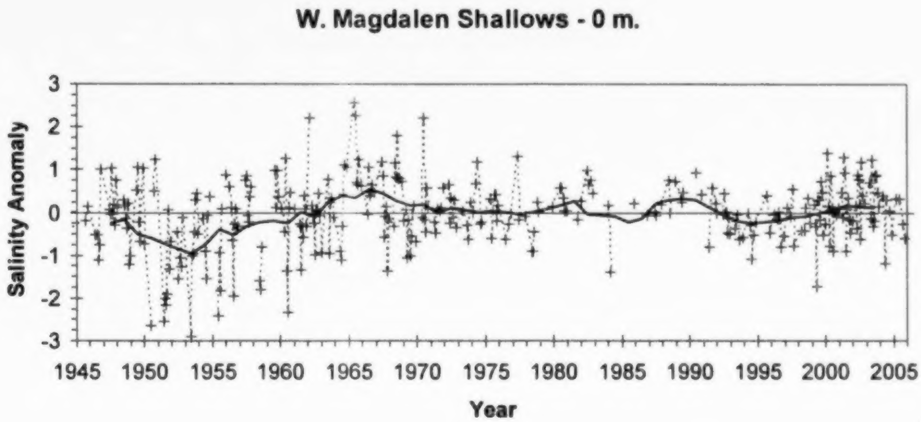


Fig. 26. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of salinity at 75 m for the western (top panel) and eastern (bottom panel) Magdalen Shallows.



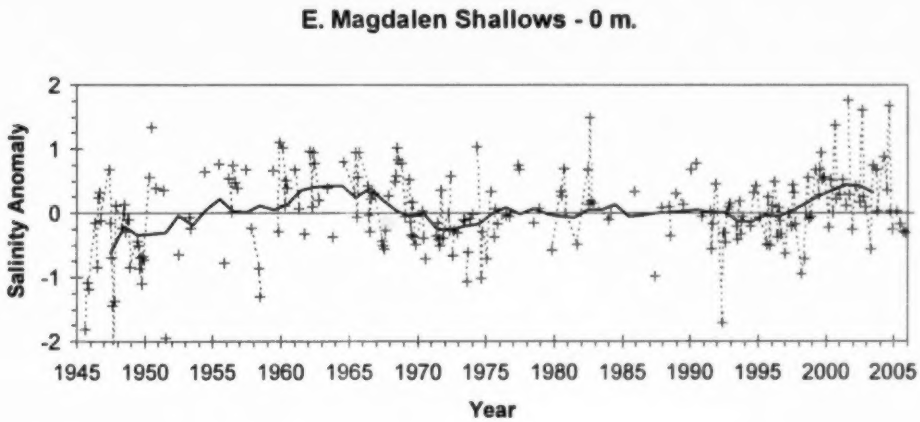


Fig. 27. The time series of the monthly (dashed line) and the 5-year running mean of the annual anomalies (solid line) of the surface salinity for the western (top panel) and eastern (bottom panel) Magdalen Shallows.

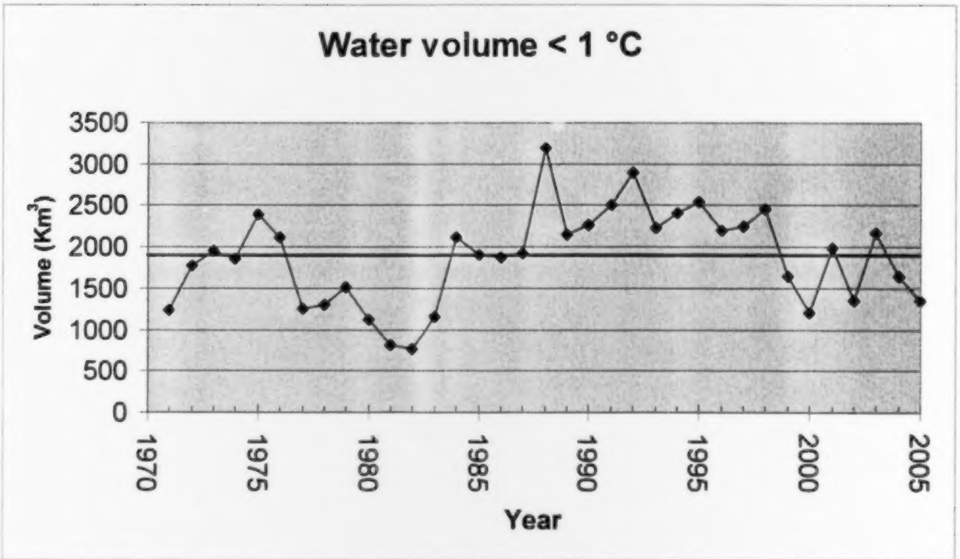


Fig. 28. Volume of the Cold Intermediate Layer in September for the Southern Gulf of St. Lawrence. The red line is the 1971-2000 long term average.